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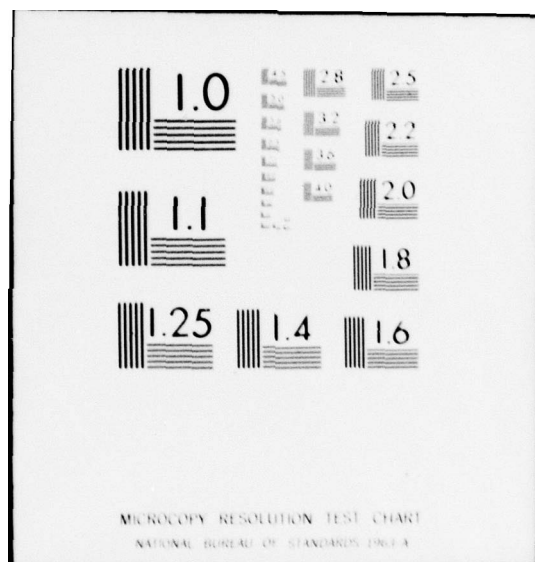
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6 GATED TV INSTRUMENTATION SYSTEM (U)

10 C. DAVID BROWN, CPT, SC
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Weapon-pointing data for the hit-probability analysis of stabilized vehicle-mounted weapon systems have long been obtained by high-speed photographic techniques, which do not provide a real-time analysis capability, as film must be processed and requires excessive data-reduction time (film reading). Infrared (ir) tracking systems, also in use, provide no image and therefore are extremely difficult to set up and align. The Gated TV (GTV) system (Figure 1) consisting of a video camera, a tracker error processor (tracker) (TEP), a video monitor, and a digital or analog recorder, will derive weapon-pointing errors as digital numbers or analog voltages proportional to angular elevation-and-azimuth errors in real time. This output can be recorded or presented directly to automatic data-processing equipment (ADPE) to obtain weapon-pointing data as a function of time. This instrumentation provides the basis for measuring target position, lead angle, and target angular rate. Utilizing such information, stabilization and tracking studies of main and secondary weapon systems are readily accomplished.

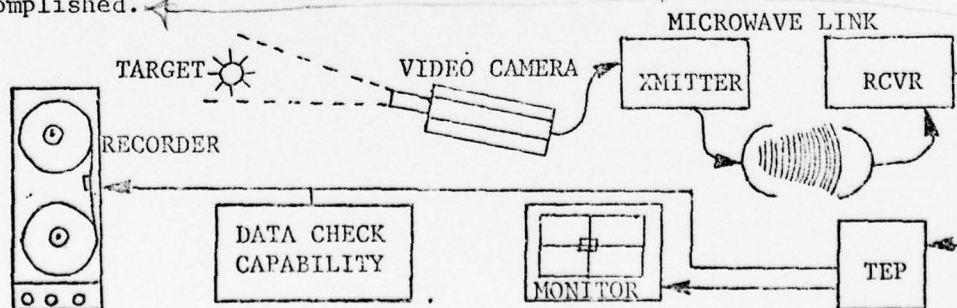


Figure 1 Block Diagram of GTV System

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Since the error data are available in real time, the test director can monitor constantly, providing close control of the test and rapidly correcting situations that might result in the loss of valuable test items or critical data; moreover, a video monitor in the system provides a picture of where the weapon is pointing. Many costly retests are thus avoided, and better control yields more viable data.

The GTV system determines the pointing angles of the weapons and fire-control systems of combat vehicles. Figure 1 is a block diagram of this system. A video camera and lens are mounted on and boresighted with the gun tube of the combat vehicle. The video picture is transmitted by cable or microwave link to an instrumentation van containing the other system components. The received composite video signal is fed to the TEP, and an annotated video signal is fed from the tracker to a video monitor. The tracker converts the target position within the video picture to digital and analog values proportional in real time to the target displacement from a predetermined boresight. These values are then recorded on tape or sent directly to the ADPE.

The video camera, long regarded as merely an imaging device, plays a primary role in the GTV system. Since the tracker input is the video signal from the camera, the camera is the transducer for the GTV system. The video camera must be stable, rugged, and linear, and have a wide dynamic range to ensure these characteristics in the overall system performance. The lens on the video camera must also possess the same characteristics. Changing the focal length of the lens changes the field of view (FOV) of the video camera. Since the tracker resolution is a fixed percentage (0.4% vertical) of the FOV, the resolution or accuracy of the system is a function of the focal length of the lens. For example, a 20-inch (508-mm) (focal length) lens on a 1-inch (25.4-mm) vidicon camera yields a system vertical FOV of 19.5 mils and an accuracy of ± 0.08 mil; an 80-inch (2032-mm) lens yields an accuracy of ± 0.02 mil but an FOV of only 4.8 mils. A trade off exists

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between the desired accuracy and the FOV required to accommodate system errors and dynamics, lead angles, superelevation, etc.

The tracker accepts as its input the video signal from the camera. This video signal is a high-frequency analog-voltage stream of sequential left-to-right top-to-bottom (ignoring image reversal by the lens) scans of the camera image area. The tracker searches this input signal for a discontinuity: a voltage higher than an operator-established threshold, meaning a target brighter than the background; or a voltage lower than a threshold, meaning a target darker than the background. By identifying the target position in the input stream, the tracker determines the target position in the FOV. This operation is accomplished at the standard video-field (there are two fields to every 2:1 interlaced frame) scanning rate of 60 times per second. Since the standard video line-scanning rate is approximately 250 lines per field (500 per frame) in the active image area, maximum resolution is 1 line in 250, or 0.4% of the FOV. This resolution can be increased by higher scan rates; for instance, another standard scanning rate is 800 lines per frame, 400 per field, yielding a resolution of 1 line in 400 or 0.25% of the FOV. The trade off is that the higher scanning rate is somewhat specialized and the associated equipment is considerably more expensive and less available. There are applications, however, where the higher resolution is required, such as tracking through the gunner's sight.

The tracker is capable of edge or centroid tracking. In the edge mode the operator can select the leading edge of the target that he/she wants to be tracked. This mode is particularly useful for large targets that may extend out of the FOV. In the centroid mode the tracker digitally performs the mathematical operations:

$$\bar{X} = Xda / \int dA \quad \bar{Y} = YdA / \int dA$$

to locate and track the center of area (A) of the target.

A tracking gate limits the processing of target information to an area automatically adjustable in size from 5% to 80% of the FOV. The gate can be manually positioned or, using an electronic servo loop, the gate will position itself such that the center of the gate coincides with the tracking point (edge or centroid) in the preceding video field; thus, in the current video field, the tracker will only search for the new target position in an area the size of the gate around the last known target position. While somewhat limiting frequency response with small gate sizes the gate greatly enhances the system noise immunity and tracking ability.

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The tracker also generates a reticle display on the monitor, indicating the center of the FOV or the boresight reference point. This reticle aids in system setup and alignment. An additional feature allows the zero reference point to be moved from the center of the FOV and positioned by the operator.

The tracker has three different outputs. The video output produces the display on the video monitor, aiding system setup, alignment, and operation. The digital outputs are the chief error output signals, as all internal processing is digital, and digital data are the most desirable for further processing. These digital signals are 1's complement or 2's complement, 8 to 12 bit (depending on the resolution determined by the scan rate) binary numbers, indicating the target position in a cartesian coordinate fashion. The addition of analog-to-digital converters within the tracker generates alternate analog outputs varying between -5 and +5 volts, proportional to the target position. These analog outputs provide a convenient means of checking field data. Two digital displays on the front panel of the tracker also provide convenient readouts of the error signals.

The feasibility of the GTV system was to be tested by evaluating the system with the following criteria: the system should function as anticipated and provide at least the same amount of data as is derived from the high-speed photographic techniques and its tracking systems; the system should be practical from a standpoint of ease of installation and operation; the system accuracy under field instrumentation conditions should be at least that demanded by the tracking and stabilizer testing for which it would be used.

LABORATORY TESTS

Not only was the GTV system a new instrumentation system, but the video camera was an entirely new form of transducer to be used for data collection. Thus the video camera and TEP, the main components of the GTV system, first underwent extensive laboratory evaluation designed to verify the operation and accuracy through a point-by-point analysis of predicted outputs versus actual outputs. Laboratory tests were designed to evaluate system static linearity, dynamic linearity, frequency response and phase lag, and mechanical stability in a vibration environment. The laboratory tests were designed to uncover potential problem areas before field testing and to provide a data base that would minimize the data to be evaluated during field testing. This would allow the chief concerns of the field testing to be ease of installation and operation, system durability, and field suitability.

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The objective of the static system evaluation was to determine a correlation between the target position in the FOV and the output of the system. The evaluation of the complete system was conducted by testing the tracker for linearity and then adding the other components of the system, camera and monitor, and evaluating the system as a whole as each component was added.

To test the linearity of the tracker, a calibrated video-test-pattern generator was used to generate a video signal consisting of a linear dot array covering the entire FOV. The dots in the linear array were assigned numerical labels in a cartesian coordinate fashion. A linear regression analysis was performed on the tracker output values for the points as a numerical evaluation of tracker linearity.

An industry standard procedure exists for evaluating the linearity of video cameras. This procedure utilizes an EIA Standard Video Linearity Test Chart, a video bar-dot mixer, and a video monitor. The test pattern is placed so that it exactly fills the FOV of the video camera. The video output is run through a bar-dot mixer, where it is mixed with a calibrated electronic grid and is then fed to the video monitor. By noting the alignment (on the monitor) between the test pattern and the electronic grid, the camera linearity can be verified or adjusted to 1% or less of the picture area. During this test a new solid-state image-device video camera was examined. The camera used a charge-coupled device (CCD) for the image sensor, which was a 520 by 344 linear array of light-sensitive elements. The linearity of this camera was verified to well within 1% of the picture area. Because the picture on the CCD camera is formed, not by a sweeping beam but by fixed elements, this camera was considered to be inherently stable in linearity and picture aspect ratio. For this reason, this camera was used when possible during the evaluation of the GTV system; however, much testing was accomplished before the CCD camera was available.

The objective of the dynamic system linearity test was to make the same linearity evaluation as the static system linearity test, but this time to use a moving target. This test is an extremely valuable laboratory test because all test scenarios in which this instrumentation would be used would be dynamic. A linear array of 29 computer-addressable light emitting diodes (LEDs) (Figure 2) was placed completely within the FOV of a CCD solid-state video camera, connected to the tracker. The LEDs were lighted in succession by the computer and the tracker digital output was sampled by the computer and stored in the memory with the LED driving function for later processing.

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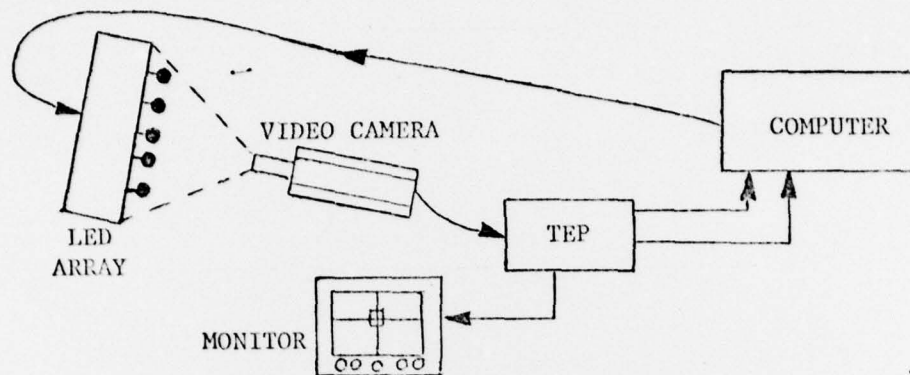


Figure 2 Dynamic Linearity and Frequency Evaluation Setup

Since the LEDs were arranged in a linear array, the tracker outputs could be compared to the known positions of the LEDs to verify the tracker dynamic linearity. The linearity of the tracker outputs was verified using the same linear regression analysis as in the static evaluation. Each LED was activated 30 times in succession and the array was swept in a sawtooth wave fashion so that 1000 data points (3.7 milliseconds apart) were taken. As discussed in following paragraphs, phase lag was evident in the tracker outputs during this dynamic testing. The linear regression routine accounted for this phase lag by iterating the regression subroutine, each time stepping the tracker output data back one sample interval, until the standard deviation was minimized, indicating the best fit. Because field data should never be discontinuous, as were the discrete LED positions, the linear regression analysis was performed on the time-displaced data, disregarding data points falling at the transitions in LED positions.

Because the tracking system is to be used to track moving or stationary targets in a dynamic (moving-vehicle, vibration, etc.) environment, the frequency response of the system is an essential parameter and could be a limiting factor for some applications. The term "break lock" is used when the speed of target movement in the FOV has exceeded the tracking ability of the TEP. Since the TEP inserts a gate and a target flag into the video signal going to the monitor, which follows the target when it is tracking properly, breaking lock is readily visible to the operator. Breaking lock often (and for extended periods during data acquisition) is extremely undesirable as data output during this time is meaningless.

Phase lag is also an important parameter, as there is a delay

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between target acquisition and the location and presentation of the error outputs. This phase lag must be known where precise time correlation between target position and other data outputs is essential to the format of the test for which this information is being used.

A basic understanding of the theory of operation of the TEP leads to the following hypothesis of system frequency response and phase lag:

a. The output of the TEP is updated once per field or 60 times per second; therefore, the maximum theoretical frequency for proper track (meaning target-deflection reconstruction from the tracker output) of pure sine-wave deflection would be 30 Hz. Since this Nyquist sampling rate is theoretical and would not yield a desirable output for test data, it is suspected that the maximum frequency should be considered as substantially lower than 30 Hz, or as low as 10 Hz.

b. Because of the left-to-right top-to-bottom (of the reproduced picture) sweep of the video image device in the camera, target-acquisition time decreases as the target moves up and left in the FOV. The best case of time lag in target acquisition was when the target was in the lower right corner of the FOV (one sample) and in the upper left corner (succeeding sample). In this case the output lag would be the vertical retrace time plus two horizontal sweep times (two horizontal sweeps of the target are required for target acquisition) or approximately 627 microseconds. The worst case would be when the target moved from upper left to lower right. The time lag here would be the time required for two vertical scans minus two horizontal scans plus one vertical retrace, or approximately 34 milliseconds. Since all other forms of target movement are between these two extremes, with the target-movement frequency being low in most instances, the average lag of 17 milliseconds between target position and data output is probably a viable approximation, ignoring the persistence of the video image device or camera delays. Only the area within the gate is searched for target information, and the position is produced immediately following target acquisition in the edge track mode; in centroid track the target position is produced at the completion of sweeping the entire gate. This will produce differing results for rapidly varying signals.

c. Since the gate position is updated once per field and is calculated to center on the output of the preceding field, the gate will break lock if the target-deflection horizontal component during 1/60 second exceeds half the gate width or the vertical component exceeds half the gate height.

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d. Because tracking and gate display is lost as soon as any edge of the gate goes out of the FOV, the target must remain in an area of height equal to the FOV vertical dimension minus the height of the gate and in width equal to the FOV horizontal dimension minus the width of the gate.

This evaluation utilized the same method and data as the dynamic linearity test. The sweeping LED array (Figure 2) provided a good, accurately controlled simulation of a moving target, and it was easy to compare the LED driving function with the tracker output to verify frequency response and phase lag. It was decided that frequency-response measurements should be taken with the entire target deflection within the gate and the gate in the manual position, to eliminate the variable of gate size, which is operator adjustable.

Figure 3 is a sample of several plots of the LED function and the GTV outputs versus time. These plots clearly indicated that the GTV outputs lag the LED positions by a generally constant time. This lag was arrived at analytically by taking the average number of data samples that the linear regression routine had to shift the GTV output data to achieve a best fit, and multiplying that number by the sample interval. The average shift was 9.37 samples; samples were taken 3.7 milliseconds apart, indicating that the average lag is 34.7 milliseconds, approximately two video-field times.

In this experiment the LED driving function was a step function, so the GTV outputs could be considered as a step response having an average rise time of 34.7 milliseconds. Applying the commonly used formula:

$$3\text{-dB frequency} = 0.35 \div \text{rise time}$$

yields a frequency of 10 Hz. Although 3 dB is meaningless in terms of the digital processing within the tracker, this frequency could be considered to be the point above which breaking lock would occur.

It was anticipated that the GTV system would be used extensively for an evaluation of vehicular-mounted systems, an environment that would subject the video camera and lens to considerable vibration. To evaluate the performance of the system in this environment, the camera, lens, and mount were firmly mounted on a package tester and then shaken in such a way that the test items were subjected to accelerations very similar to (if not more severe than) those recorded on the camera position of a moving vehicle.

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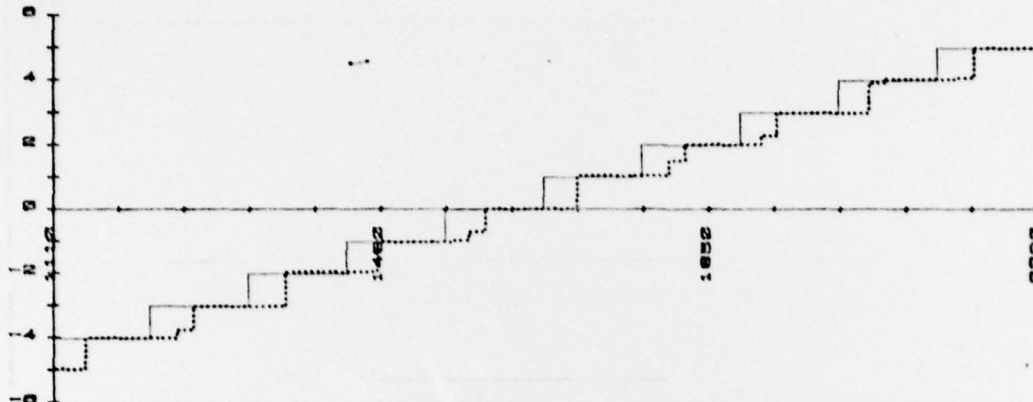


FIGURE 2. DIGITAL LED POSITION AND LR SCALED GTV CENTROID TRACK
AZ OUTPUT VS TIME IN MSEC. 1 SD OF GTV LR = 0.1 % OF FULL SCALE
GTV OUTPUT LAG = 37.5 MSEC

DISCUSSION OF LABORATORY TESTS

Because most field recording-and-measuring devices are calibrated to within only 1% of full scale, this value was chosen as a criterion by which to judge the overall accuracy of the GTV system. The laboratory static-linearity tests demonstrate that the GTV system (tracker and camera) is linear within 1% of full scale, because all differences between the observed outputs and the linear regression predicted outputs are less than 0.05 volt. Dynamic linearity was calculated using a 2.5 S (standard deviation) estimate level, a strict linearity criterion, predicting that 99% of the time the output will be within the calculated linearity. For centroid track azimuth and elevation, this value was within 1%; for edge track azimuth and elevation, this value was slightly greater than 1% but was within 2%. The choice of a more lenient 1 S or 1.5 S level would have brought the edge-track data within 1% linearity. It is felt that the slightly worse linearity performance of the tracker in the edge mode is because the LEDs were of varying brightness. Any concentrated light source blooms somewhat on a video sensor, depending on the brightness, and sources of varying brightness appear to be different sizes; therefore, the target edge position, in relation to the center, differs with respect to source brightness, greatly affecting edge track while not appreciably affecting centroid track.

System frequency response was verified to the predicted 10 Hz, with the gate being stationary in manual track and all target movement being contained within the gate. The average phase lag was experimentally derived as approximately 35 milliseconds instead of the

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expected 17. Slight persistence was perceptible with the CCD camera used during the phase-lag experiment. This slight persistence is noticeable and was experimentally verified as approximately the same for all the video image devices used with the GTV system. Because any persistence or lag in the image sensor carries over into the next field scan, this lag tends to be a quantized time equal to one field scan (approximately 17 milliseconds). This plus the 17 millisecond tracker lag equals 34 milliseconds, within one computer sample time (3.7 milliseconds) of the experimentally derived lag of approximately 35 milliseconds, making the predicted and experimental numbers equal within the sampling accuracy.

FIELD TESTS

The chief purpose of the field tests was to examine the practicality of the GTV system for field instrumentation. During system evaluation, the GTV system was successfully installed on and removed from several different types of vehicles; this required no more time than was involved with photometric techniques. The GTV did not affect vehicle operation, nor did the vehicle affect operation or accuracy of the GTV. Packaging was rugged and convenient enough for field usage. The most practical installation seemed to be with the video camera mounted on the gun tube with its video output sent by microwave link to a data van containing the tracker, monitor, and recorder. The camera and microwave transmitter are both ruggedized units and did function without a problem during all testing. This setup required no operator on board the vehicle, as tracker monitoring, data logging, and recording were all accomplished by one person in the data van. A summary of manpower savings and associated monetary savings during several tracking and stabilizer programs conducted during FY76 is included as Figure 4.

	<u>Savings in \$1000</u>
Data Acquisition (per test)	
Typical tracking test	
previously required 6 weeks, 6 men, \$15,000	
GTV requires 2 weeks, 6 men, \$5,000	Savings of 10
Typical stabilizer test (same as above)	10
<u>Data Reduction (tracking or stabilizer) (per test)</u>	<u>10</u>
Major Programs (data acquisition and reduction combined)	
Quick Fox (combined tracking/stabilizer/target acquisition series)	200
XM-1 Tank (4 tracking, 4 stabilizer tests)	160
MICV (3 tracking, 10 stabilizer tests)	120
M-60 Tank (4 tracking, 10 stabilizer tests)	280
Graph Angle (air defense tracking series)	<u>200</u>
Total Major Program Savings	<u>960</u>

Figure 4 Summary of GTV Monetary Savings FY76

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The parameters evaluated during laboratory testing were examined at various times during field testing. An analysis of this data would indicate system degradation, mechanical or electrical drift, or an operator's inability to make the system function properly in the field. It was apparent from field data and results that there was no drift or linearity degradation beyond the 1.0% tolerance specified earlier. This was true during linearity and boresight (zero) checks during all phases of field testing.

An inspection of the tracking waveforms on a playback oscillograph of analog field data showed few discontinuities that indicated loss of lock. The situations with discontinuities were remedied by a change in the focal length of the lens to increase the FOV. These were the only frequency-response problems; an examination of the waveforms indicated that the majority of the frequencies were well below the 10 Hz response determined during laboratory testing. Since the frequency responses of the turret systems of the vehicles under test were well below 10 Hz, the frequency components at 10 Hz or above in the error waveforms were generally not meaningful tracking data.

CONCLUSIONS

The following conclusions were reached as a result of the evaluation of the GTV instrumentation system:

- a. The GTV system is linear and stable in both static and vibration or dynamic environments to within 1.0% of the FOV. The accuracy and precision of the GTV system is, therefore, greater than the maximum 1.0% tolerances of the data recording and processing systems and the 1.0% tolerances required for tracking and stabilizer testing.
- b. Dynamic response is a function of the FOV of the video camera. Changes in focal length affect dynamic response and measurement precision inversely, so the focal length of the lens must be carefully tailored to the particular testing situation.
- c. Dynamic response is also affected by gate size; increasing the gate size increases the dynamic response, but also decreases optical signal-to-noise performance. Size also must be tailored to the particular testing situation, but can easily be changed by the operator during the test for best results.
- d. The GTV system presented no unreasonable problems in installation or operation during field testing. The video-monitoring capability was most valuable and made immediate test-progress analysis possible. The GTV system therefore appears to be a viable field instrumentation system producing good data suitable for direct input

to the ADPE or any data-recording system.

e. Because camera linearity greatly affects data and can vary with time and environment, linearity and other camera specifications must be verified at regular intervals. This requirement is important to vidicon cameras where linearity and aspect ratio are dependent on the electronics that sweep the beam across the vidicon faceplate, but should also be applied to solid-state cameras at less frequent intervals.

FURTHER APPLICATIONS OF VIDEO TO INSTRUMENTATION

The GTV system represented one of the first applications of video techniques for instrumentation instead of merely viewing. Evaluation of the system demonstrated that the video camera is a viable transducer for dynamic and static position data acquisition. The GTV's success has led to many unique applications of video in the instrumentation field. These applications include the: 1) Automated Video Target Scoring System, 2) Video Muzzle Position System, 3) Video Surf Measurement and Analysis System, and 4) Automatic Video Shell Fragment Area and Velocity Measuring Systems.

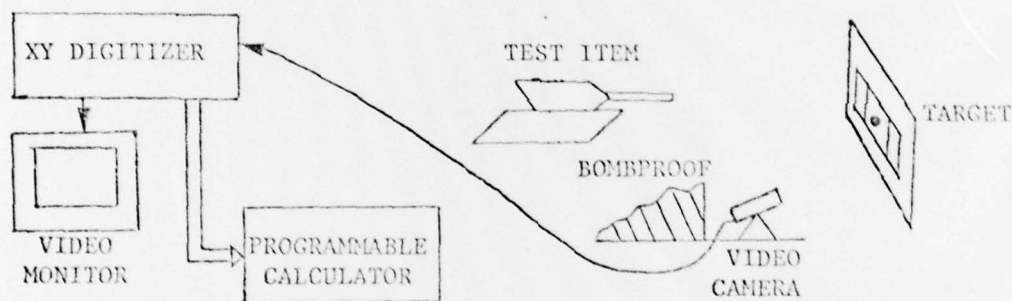


Figure 5 Automated Video Target Scoring System

The Automated Video Target Scoring System (AVTSS) utilizes a video camera, a programmable calculator, and a video XY position digitizer (Figure 5). The XY digitizer is similar to the TEP in the GTV system except that, instead of tracking a target point, an operator positions a cursor in the video FOV and the X and Y positions of the cursor are output as digital words. The video camera is aimed at a cloth target used during testing large caliber weapons. An interactive calculator program steps the operator through appropriate calibration such that distances in the video FOV can be related to actual distances at the target. The gunner's aim point is digitized and then the cursor is placed over the images of holes made in the target by the rounds fired and thus the target is scored remotely. At the completion of firing the calculator outputs the mean and standard deviation of the shot group. The AVTSS eliminates the need for measuring the cloth

target directly thereby saving time and manpower to drive downrange, lower, score and raise the target, and return.

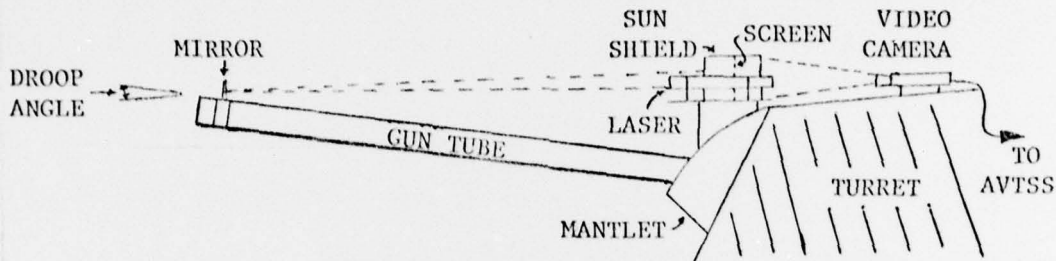


Figure 6 Video Muzzle Position System

The Video Muzzle Position System (VMPS) incorporates the AVTSS to measure gun muzzle movement with respect to the mantlet over a period of time. A small continuous wave laser and translucent screen are mounted on the gun muzzle (Figure 6). A mirror is fastened to the muzzle so that the laser beam is reflected back to the translucent screen. The video camera of the AVTSS is aimed at the back side of the translucent screen and readings are taken by positioning the cursor over the image formed by the reflected laser beam on the screen. The calculator output is angular displacement of the muzzle in mils or other desired scientific units referenced to a position taken at the beginning of testing. Once again, application of video techniques allows this data to be acquired remotely and logged more accurately and rapidly than with other techniques.

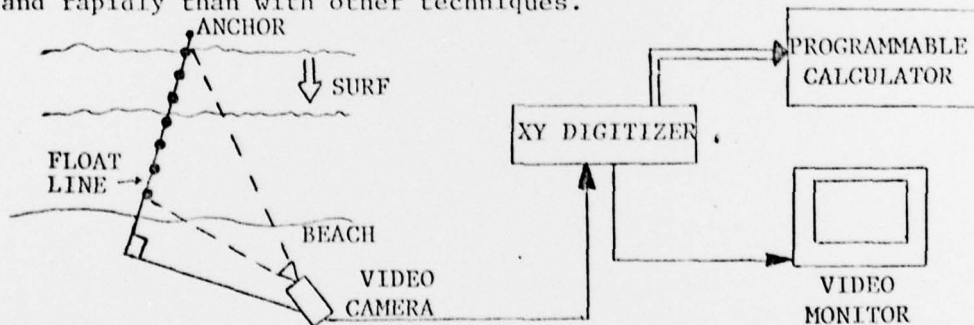


Figure 7 Video Surf Measurement and Analysis System

The Video Surf Measurement and Analysis System was developed to measure the height, velocity, and period of plunging surf throughout an entire surf zone. Testing of a military landing craft required that this data be obtained, however all wave measuring systems in existence prior to the development of the video based system were incapable of measuring surf and could only obtain data for a single location.

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A float line is anchored on the beach and beyond the surf zone (Figure 7). The same components of the AVTSS are utilized with the camera positioned on the beach such that its FOV covers the entire portion of the float line in the surf zone. Previously determined angles and distances are entered into the calculator during calibration. An operator positions the cursor at the peak of a breaker and the float line and digitizes this position. After the breaker passes the cursor is then moved vertically to the float line as it rests at the low water level. The calculator program then accomplishes the necessary trigonometry to calculate the height of the breaker. The addition of a digital time base allows the system to yield breaker velocity by digitizing the same wave crest at two positions, and period, by digitizing two succeeding wave crests at a single position. The calculator also logs the data and performs any analysis as required by the test program.

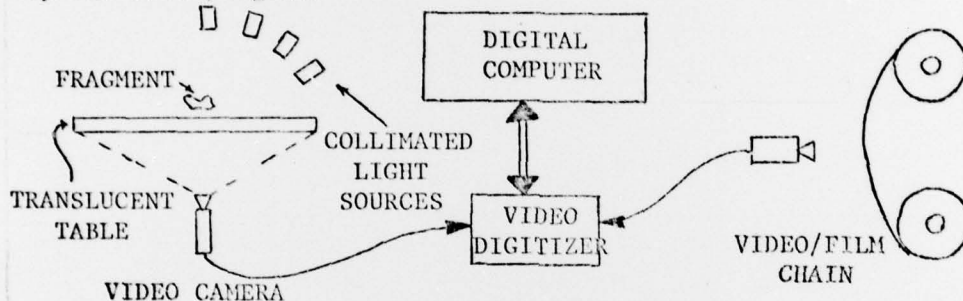


Figure 8 Automatic Video Shell Fragment Area and Velocity Measuring Systems

The Automatic Video Shell Fragment Area and Velocity Measuring Systems are presently under development. Both systems utilize a video camera, a programmable calculator, and a video digitizer (Figure 8). The digitizer allows a single video field to be converted to a matrix of digital words corresponding to the gray scale value of each picture element (pixel) comprising the entire FOV.

To measure shell fragment velocity, a shell is exploded in an arena with dark vinyl sheeting along one side. As the fragments pierce the sheeting a high speed film camera records the holes as light passes through the sheeting from a bank of flash bulbs on the inside. Reading the film frame by frame to determine fragment time and position for velocity calculation is presently a long and arduous task. The video based system will present each film frame to the video camera, digitize the picture, and compare the new picture matrix with that stored in memory from the previous frame thus determining new fragment holes and their location. Data analysis that presently takes days would be accomplished in minutes with the video based system.

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The same system can also measure fragment area. Collimated light sources at several angles project silhouettes of the fragment onto a translucent table above which the fragment is suspended. A video camera is placed below the table so that the silhouettes become video images. These video images are digitized and the computer can then determine the area of the various projections and thus the size of the fragment.

Presently, applications of video to instrumentation are limited by the speed and resolution of the video image devices. As research improves these parameters, the applications of video to instrumentation will greatly increase. Image correlation trackers will become more feasible along with much more extensive processing of the video image. There is an enormous amount of data yet to be extracted from the processing of a video image. The GTV evaluation proves the effectiveness of a video based instrumentation system, and the further applications discussed here are only the beginning.

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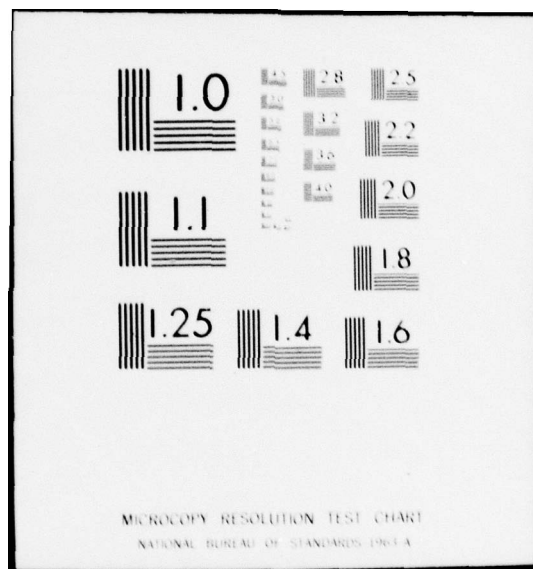
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Weapon-pointing data for the hit-probability analysis of stabilized vehicle-mounted weapon systems have long been obtained by high-speed photographic techniques, which do not provide a real-time analysis capability, as film must be processed and requires excessive data-reduction time (film reading). Infrared (ir) tracking systems, also in use, provide no image and therefore are extremely difficult to set up and align. The Gated TV (GTV) system (Figure 1) consisting of a video camera, a tracker error processor (tracker) (TEP), a video monitor, and a digital or analog recorder, will derive weapon-pointing errors as digital numbers or analog voltages proportional to angular elevation-and-azimuth errors in real time. This output can be recorded or presented directly to automatic data-processing equipment (ADPE) to obtain weapon-pointing data as a function of time. This instrumentation provides the basis for measuring target position, lead angle, and target angular rate. Utilizing such information, stabilization and tracking studies of main and secondary weapon systems are readily accomplished.

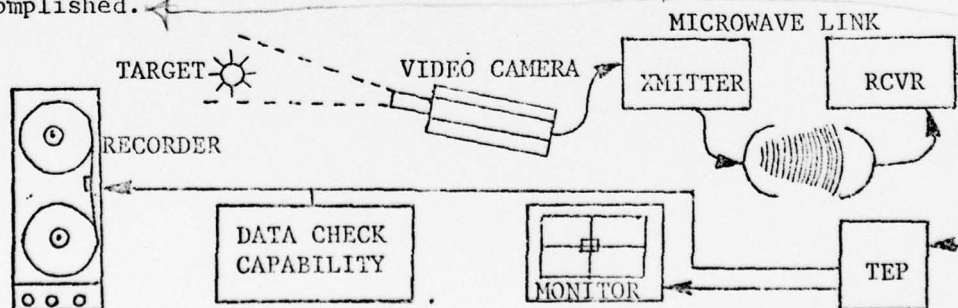


Figure 1 Block Diagram of GTV System

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Since the error data are available in real time, the test director can monitor constantly, providing close control of the test and rapidly correcting situations that might result in the loss of valuable test items or critical data; moreover, a video monitor in the system provides a picture of where the weapon is pointing. Many costly retests are thus avoided, and better control yields more viable data.

The GTV system determines the pointing angles of the weapons and fire-control systems of combat vehicles. Figure 1 is a block diagram of this system. A video camera and lens are mounted on and boresighted with the gun tube of the combat vehicle. The video picture is transmitted by cable or microwave link to an instrumentation van containing the other system components. The received composite video signal is fed to the TEP, and an annotated video signal is fed from the tracker to a video monitor. The tracker converts the target position within the video picture to digital and analog values proportional in real time to the target displacement from a predetermined boresight. These values are then recorded on tape or sent directly to the ADPE.

The video camera, long regarded as merely an imaging device, plays a primary role in the GTV system. Since the tracker input is the video signal from the camera, the camera is the transducer for the GTV system. The video camera must be stable, rugged, and linear, and have a wide dynamic range to ensure these characteristics in the overall system performance. The lens on the video camera must also possess the same characteristics. Changing the focal length of the lens changes the field of view (FOV) of the video camera. Since the tracker resolution is a fixed percentage (0.4% vertical) of the FOV, the resolution or accuracy of the system is a function of the focal length of the lens. For example, a 20-inch (508-mm) (focal length) lens on a 1-inch (25.4-mm) vidicon camera yields a system vertical FOV of 19.5 mils and an accuracy of ± 0.08 mil; an 80-inch (2032-mm) lens yields an accuracy of ± 0.02 mil but an FOV of only 4.8 mils. A trade off exists

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between the desired accuracy and the FOV required to accommodate system errors and dynamics, lead angles, superelevation, etc.

The tracker accepts as its input the video signal from the camera. This video signal is a high-frequency analog-voltage stream of sequential left-to-right top-to-bottom (ignoring image reversal by the lens) scans of the camera image area. The tracker searches this input signal for a discontinuity: a voltage higher than an operator-established threshold, meaning a target brighter than the background; or a voltage lower than a threshold, meaning a target darker than the background. By identifying the target position in the input stream, the tracker determines the target position in the FOV. This operation is accomplished at the standard video-field (there are two fields to every 2:1 interlaced frame) scanning rate of 60 times per second. Since the standard video line-scanning rate is approximately 250 lines per field (500 per frame) in the active image area, maximum resolution is 1 line in 250, or 0.4% of the FOV. This resolution can be increased by higher scan rates; for instance, another standard scanning rate is 800 lines per frame, 400 per field, yielding a resolution of 1 line in 400 or 0.25% of the FOV. The trade off is that the higher scanning rate is somewhat specialized and the associated equipment is considerably more expensive and less available. There are applications, however, where the higher resolution is required, such as tracking through the gunner's sight.

The tracker is capable of edge or centroid tracking. In the edge mode the operator can select the leading edge of the target that he/she wants to be tracked. This mode is particularly useful for large targets that may extend out of the FOV. In the centroid mode the tracker digitally performs the mathematical operations:

$$\bar{X} = Xda / \int dA \quad \bar{Y} = Yda / \int dA$$

to locate and track the center of area (A) of the target.

A tracking gate limits the processing of target information to an area automatically adjustable in size from 5% to 80% of the FOV. The gate can be manually positioned or, using an electronic servo loop, the gate will position itself such that the center of the gate coincides with the tracking point (edge or centroid) in the preceding video field; thus, in the current video field, the tracker will only search for the new target position in an area the size of the gate around the last known target position. While somewhat limiting frequency response with small gate sizes the gate greatly enhances the system noise immunity and tracking ability.

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The tracker also generates a reticle display on the monitor, indicating the center of the FOV or the boresight reference point. This reticle aids in system setup and alinement. An additional feature allows the zero reference point to be moved from the center of the FOV and positioned by the operator.

The tracker has three different outputs. The video output produces the display on the video monitor, aiding system setup, alinement, and operation. The digital outputs are the chief error output signals, as all internal processing is digital, and digital data are the most desirable for further processing. These digital signals are 1's complement or 2's complement, 8 to 12 bit (depending on the resolution determined by the scan rate) binary numbers, indicating the target position in a cartesian coordinate fashion. The addition of analog-to-digital converters within the tracker generates alternate analog outputs varying between -5 and +5 volts, proportional to the target position. These analog outputs provide a convenient means of checking field data. Two digital displays on the front panel of the tracker also provide convenient readouts of the error signals.

The feasibility of the GTV system was to be tested by evaluating the system with the following criteria: the system should function as anticipated and provide at least the same amount of data as is derived from the high-speed photographic techniques and ir tracking systems; the system should be practical from a standpoint of ease of installation and operation; the system accuracy under field instrumentation conditions should be at least that demanded by the tracking and stabilizer testing for which it would be used.

LABORATORY TESTS

Not only was the GTV system a new instrumentation system, but the video camera was an entirely new form of transducer to be used for data collection. Thus the video camera and TEP, the main components of the GTV system, first underwent extensive laboratory evaluation designed to verify the operation and accuracy through a point-by-point analysis of predicted outputs versus actual outputs. Laboratory tests were designed to evaluate system static linearity, dynamic linearity, frequency response and phase lag, and mechanical stability in a vibration environment. The laboratory tests were designed to uncover potential problem areas before field testing and to provide a data base that would minimize the data to be evaluated during field testing. This would allow the chief concerns of the field testing to be ease of installation and operation, system durability, and field suitability.

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The objective of the static system evaluation was to determine a correlation between the target position in the FOV and the output of the system. The evaluation of the complete system was conducted by testing the tracker for linearity and then adding the other components of the system, camera and monitor, and evaluating the system as a whole as each component was added.

To test the linearity of the tracker, a calibrated video-test-pattern generator was used to generate a video signal consisting of a linear dot array covering the entire FOV. The dots in the linear array were assigned numerical labels in a cartesian coordinate fashion. A linear regression analysis was performed on the tracker output values for the points as a numerical evaluation of tracker linearity.

An industry standard procedure exists for evaluating the linearity of video cameras. This procedure utilizes an EIA Standard Video Linearity Test Chart, a video bar-dot mixer, and a video monitor. The test pattern is placed so that it exactly fills the FOV of the video camera. The video output is run through a bar-dot mixer, where it is mixed with a calibrated electronic grid and is then fed to the video monitor. By noting the alignment (on the monitor) between the test pattern and the electronic grid, the camera linearity can be verified or adjusted to 1% or less of the picture area. During this test a new solid-state image-device video camera was examined. The camera used a charge-coupled device (CCD) for the image sensor, which was a 520 by 344 linear array of light-sensitive elements. The linearity of this camera was verified to well within 1% of the picture area. Because the picture on the CCD camera is formed, not by a sweeping beam but by fixed elements, this camera was considered to be inherently stable in linearity and picture aspect ratio. For this reason, this camera was used when possible during the evaluation of the GTV system; however, much testing was accomplished before the CCD camera was available.

The objective of the dynamic system linearity test was to make the same linearity evaluation as the static system linearity test, but this time to use a moving target. This test is an extremely valuable laboratory test because all test scenarios in which this instrumentation would be used would be dynamic. A linear array of 29 computer-addressable light emitting diodes (LEDs) (Figure 2) was placed completely within the FOV of a CCD solid-state video camera, connected to the tracker. The LEDs were lighted in succession by the computer and the tracker digital output was sampled by the computer and stored in the memory with the LED driving function for later processing.

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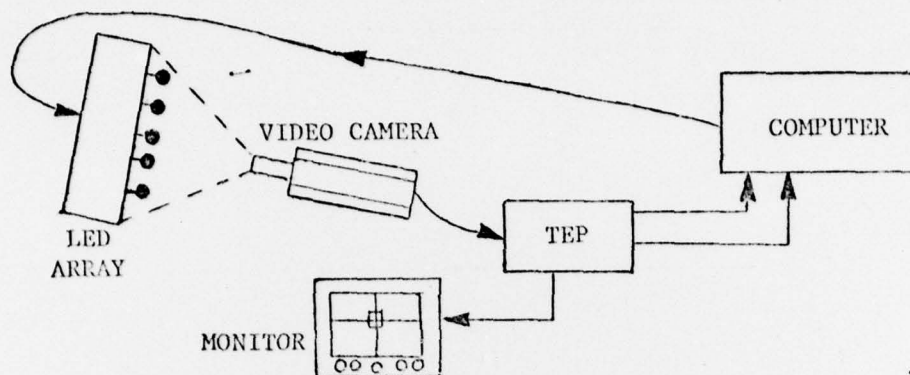


Figure 2 Dynamic Linearity and Frequency Evaluation Setup

Since the LEDs were arranged in a linear array, the tracker outputs could be compared to the known positions of the LEDs to verify the tracker dynamic linearity. The linearity of the tracker outputs was verified using the same linear regression analysis as in the static evaluation. Each LED was activated 30 times in succession and the array was swept in a sawtooth wave fashion so that 1000 data points (3.7 milliseconds apart) were taken. As discussed in following paragraphs, phase lag was evident in the tracker outputs during this dynamic testing. The linear regression routine accounted for this phase lag by iterating the regression subroutine, each time stepping the tracker output data back one sample interval, until the standard deviation was minimized, indicating the best fit. Because field data should never be discontinuous, as were the discrete LED positions, the linear regression analysis was performed on the time-displaced data, disregarding data points falling at the transitions in LED positions.

Because the tracking system is to be used to track moving or stationary targets in a dynamic (moving-vehicle, vibration, etc.) environment, the frequency response of the system is an essential parameter and could be a limiting factor for some applications. The term "break lock" is used when the speed of target movement in the FOV has exceeded the tracking ability of the TEP. Since the TEP inserts a gate and a target flag into the video signal going to the monitor, which follows the target when it is tracking properly, breaking lock is readily visible to the operator. Breaking lock often (and for extended periods during data acquisition) is extremely undesirable as data output during this time is meaningless.

Phase lag is also an important parameter, as there is a delay

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between target acquisition and the location and presentation of the error outputs. This phase lag must be known where precise time correlation between target position and other data outputs is essential to the format of the test for which this information is being used.

A basic understanding of the theory of operation of the TEP leads to the following hypothesis of system frequency response and phase lag:

a. The output of the TEP is updated once per field or 60 times per second; therefore, the maximum theoretical frequency for proper track (meaning target-deflection reconstruction from the tracker output) of pure sine-wave deflection would be 30 Hz. Since this Nyquist sampling rate is theoretical and would not yield a desirable output for test data, it is suspected that the maximum frequency should be considered as substantially lower than 30 Hz, or as low as 10 Hz.

b. Because of the left-to-right top-to-bottom (of the reproduced picture) sweep of the video image device in the camera, target-acquisition time decreases as the target moves up and left in the FOV. The best case of time lag in target acquisition was when the target was in the lower right corner of the FOV (one sample) and in the upper left corner (succeeding sample). In this case the output lag would be the vertical retrace time plus two horizontal sweep times (two horizontal sweeps of the target are required for target acquisition) or approximately 627 microseconds. The worst case would be when the target moved from upper left to lower right. The time lag here would be the time required for two vertical scans minus two horizontal scans plus one vertical retrace, or approximately 34 milliseconds. Since all other forms of target movement are between these two extremes, with the target-movement frequency being low in most instances, the average lag of 17 milliseconds between target position and data output is probably a viable approximation, ignoring the persistence of the video image device or camera delays. Only the area within the gate is searched for target information, and the position is produced immediately following target acquisition in the edge track mode; in centroid track the target position is produced at the completion of sweeping the entire gate. This will produce differing results for rapidly varying signals.

c. Since the gate position is updated once per field and is calculated to center on the output of the preceding field, the gate will break lock if the target-deflection horizontal component during 1/60 second exceeds half the gate width or the vertical component exceeds half the gate height.

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d. Because tracking and gate display is lost as soon as any edge of the gate goes out of the FOV, the target must remain in an area of height equal to the FOV vertical dimension minus the height of the gate and in width equal to the FOV horizontal dimension minus the width of the gate.

This evaluation utilized the same method and data as the dynamic linearity test. The sweeping LED array (Figure 2) provided a good, accurately controlled simulation of a moving target, and it was easy to compare the LED driving function with the tracker output to verify frequency response and phase lag. It was decided that frequency-response measurements should be taken with the entire target deflection within the gate and the gate in the manual position, to eliminate the variable of gate size, which is operator adjustable.

Figure 3 is a sample of several plots of the LED function and the GTV outputs versus time. These plots clearly indicated that the GTV outputs lag the LED positions by a generally constant time. This lag was arrived at analytically by taking the average number of data samples that the linear regression routine had to shift the GTV output data to achieve a best fit, and multiplying that number by the sample interval. The average shift was 9.37 samples; samples were taken 3.7 milliseconds apart, indicating that the average lag is 34.7 milliseconds, approximately two video-field times.

In this experiment the LED driving function was a step function, so the GTV outputs could be considered as a step response having an average rise time of 34.7 milliseconds. Applying the commonly used formula:

$$3\text{-dB frequency} = 0.35 \div \text{rise time}$$

yields a frequency of 10 Hz. Although 3 dB is meaningless in terms of the digital processing within the tracker, this frequency could be considered to be the point above which breaking lock would occur.

It was anticipated that the GTV system would be used extensively for an evaluation of vehicular-mounted systems, an environment that would subject the video camera and lens to considerable vibration. To evaluate the performance of the system in this environment, the camera, lens, and mount were firmly mounted on a package tester and then shaken in such a way that the test items were subjected to accelerations very similar to (if not more severe than) those recorded on the camera position of a moving vehicle.

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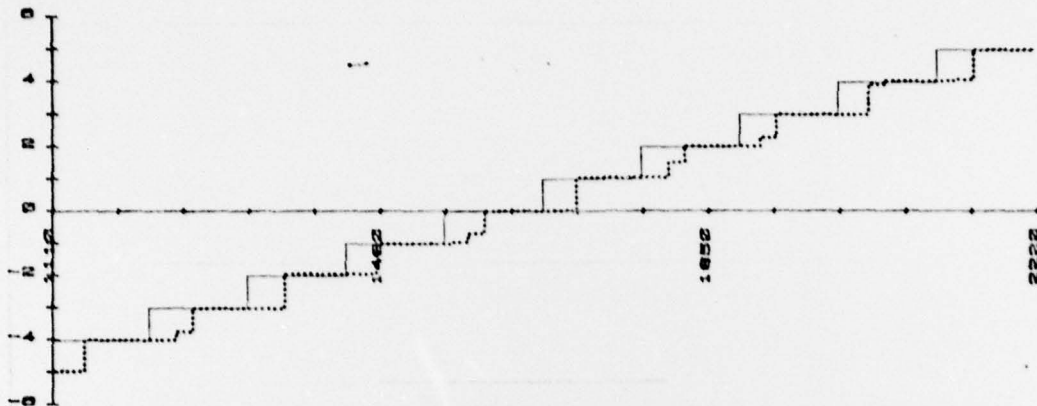


FIGURE 2. DIGITAL LED POSITION AND LR SCALED GTV CENTROID TRACK
AZ OUTPUT VS TIME IN MSEC. 1 SD OF GTV LR= 0.1 % OF FULL SCALE
GTV OUTPUT LAG = 37.5 MSEC

DISCUSSION OF LABORATORY TESTS

Because most field recording-and-measuring devices are calibrated to within only 1% of full scale, this value was chosen as a criterion by which to judge the overall accuracy of the GTV system. The laboratory static-linearity tests demonstrate that the GTV system (tracker and camera) is linear within 1% of full scale, because all differences between the observed outputs and the linear regression predicted outputs are less than 0.05 volt. Dynamic linearity was calculated using a 2.5 S (standard deviation) estimate level, a strict linearity criterion, predicting that 99% of the time the output will be within the calculated linearity. For centroid track azimuth and elevation, this value was within 1%; for edge track azimuth and elevation, this value was slightly greater than 1% but was within 2%. The choice of a more lenient 1 S or 1.5 S level would have brought the edge-track data within 1% linearity. It is felt that the slightly worse linearity performance of the tracker in the edge mode is because the LEDs were of varying brightness. Any concentrated light source blooms somewhat on a video sensor, depending on the brightness, and sources of varying brightness appear to be different sizes; therefore, the target edge position, in relation to the center, differs with respect to source brightness, greatly affecting edge track while not appreciably affecting centroid track.

System frequency response was verified to the predicted 10 Hz, with the gate being stationary in manual track and all target movement being contained within the gate. The average phase lag was experimentally derived as approximately 35 milliseconds instead of the

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expected 17. Slight persistence was perceptible with the CCD camera used during the phase-lag experiment. This slight persistence is noticeable and was experimentally verified as approximately the same for all the video image devices used with the GTV system. Because any persistence or lag in the image sensor carries over into the next field scan, this lag tends to be a quantized time equal to one field scan (approximately 17 milliseconds). This plus the 17 millisecond tracker lag equals 34 milliseconds, within one computer sample time (3.7 milliseconds) of the experimentally derived lag of approximately 35 milliseconds, making the predicted and experimental numbers equal within the sampling accuracy.

FIELD TESTS

The chief purpose of the field tests was to examine the practicality of the GTV system for field instrumentation. During system evaluation, the GTV system was successfully installed on and removed from several different types of vehicles; this required no more time than was involved with photometric techniques. The GTV did not affect vehicle operation, nor did the vehicle affect operation or accuracy of the GTV. Packaging was rugged and convenient enough for field usage. The most practical installation seemed to be with the video camera mounted on the gun tube with its video output sent by microwave link to a data van containing the tracker, monitor, and recorder. The camera and microwave transmitter are both ruggedized units and did function without a problem during all testing. This setup required no operator on board the vehicle, as tracker monitoring, data logging, and recording were all accomplished by one person in the data van. A summary of manpower savings and associated monetary savings during several tracking and stabilizer programs conducted during FY76 is included as Figure 4.

	<u>Savings in \$1000</u>
Data Acquisition (per test)	
Typical tracking test	
previously required 6 weeks, 6 men, \$15,000	
GTV requires 2 weeks, 6 men, \$5,000	Savings of 10
Typical stabilizer test (same as above)	10
<u>Data Reduction (tracking or stabilizer) (per test)</u>	<u>10</u>
Major Programs (data acquisition and reduction combined)	
Quick Fox (combined tracking/stabilizer/target acquisition series)	200
XM-1 Tank (4 tracking, 4 stabilizer tests)	160
MICV (3 tracking, 10 stabilizer tests)	120
M-60 Tank (4 tracking, 10 stabilizer tests)	280
Graph Angle (air defense tracking series)	<u>200</u>
Total Major Program Savings	<u>960</u>

Figure 4 Summary of GTV Monetary Savings FY76

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The parameters evaluated during laboratory testing were examined at various times during field testing. An analysis of this data would indicate system degradation, mechanical or electrical drift, or an operator's inability to make the system function properly in the field. It was apparent from field data and results that there was no drift or linearity degradation beyond the 1.0% tolerance specified earlier. This was true during linearity and boresight (zero) checks during all phases of field testing.

An inspection of the tracking waveforms on a playback oscillograph of analog field data showed few discontinuities that indicated loss of lock. The situations with discontinuities were remedied by a change in the focal length of the lens to increase the FOV. These were the only frequency-response problems; an examination of the waveforms indicated that the majority of the frequencies were well below the 10 Hz response determined during laboratory testing. Since the frequency responses of the turret systems of the vehicles under test were well below 10 Hz, the frequency components at 10 Hz or above in the error waveforms were generally not meaningful tracking data.

CONCLUSIONS

The following conclusions were reached as a result of the evaluation of the GTV instrumentation system:

- a. The GTV system is linear and stable in both static and vibration or dynamic environments to within 1.0% of the FOV. The accuracy and precision of the GTV system is, therefore, greater than the maximum 1.0% tolerances of the data recording and processing systems and the 1.0% tolerances required for tracking and stabilizer testing.
- b. Dynamic response is a function of the FOV of the video camera. Changes in focal length affect dynamic response and measurement precision inversely, so the focal length of the lens must be carefully tailored to the particular testing situation.
- c. Dynamic response is also affected by gate size; increasing the gate size increases the dynamic response, but also decreases optical signal-to-noise performance. Size also must be tailored to the particular testing situation, but can easily be changed by the operator during the test for best results.
- d. The GTV system presented no unreasonable problems in installation or operation during field testing. The video-monitoring capability was most valuable and made immediate test-progress analysis possible. The GTV system therefore appears to be a viable field instrumentation system producing good data suitable for direct input

to the ADPE or any data-recording system.

e. Because camera linearity greatly affects data and can vary with time and environment, linearity and other camera specifications must be verified at regular intervals. This requirement is important to vidicon cameras where linearity and aspect ratio are dependent on the electronics that sweep the beam across the vidicon faceplate, but should also be applied to solid-state cameras at less frequent intervals.

FURTHER APPLICATIONS OF VIDEO TO INSTRUMENTATION

The GTV system represented one of the first applications of video techniques for instrumentation instead of merely viewing. Evaluation of the system demonstrated that the video camera is a viable transducer for dynamic and static position data acquisition. The GTV's success has led to many unique applications of video in the instrumentation field. These applications include the: 1) Automated Video Target Scoring System, 2) Video Muzzle Position System, 3) Video Surf Measurement and Analysis System, and 4) Automatic Video Shell Fragment Area and Velocity Measuring Systems.

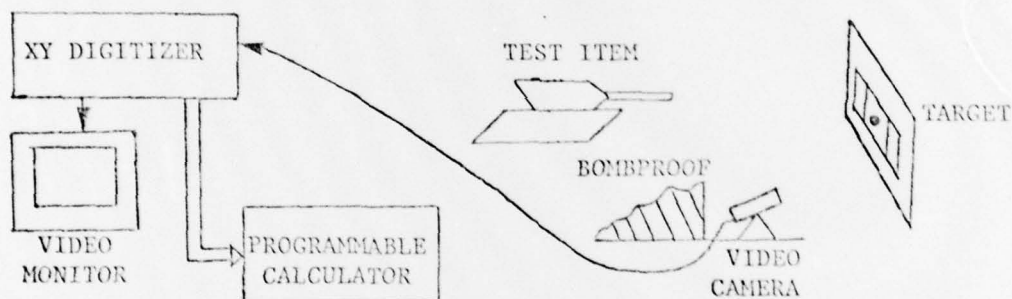


Figure 5 Automated Video Target Scoring System

The Automated Video Target Scoring System (AVTSS) utilizes a video camera, a programmable calculator, and a video XY position digitizer (Figure 5). The XY digitizer is similar to the TEP in the GTV system except that, instead of tracking a target point, an operator positions a cursor in the video FOV and the X and Y positions of the cursor are output as digital words. The video camera is aimed at a cloth target used during testing large caliber weapons. An interactive calculator program steps the operator through appropriate calibration such that distances in the video FOV can be related to actual distances at the target. The gunner's aim point is digitized and then the cursor is placed over the images of holes made in the target by the rounds fired and thus the target is scored remotely. At the completion of firing the calculator outputs the mean and standard deviation of the shot group. The AVTSS eliminates the need for measuring the cloth

target directly thereby saving time and manpower to drive downrange, lower, score and raise the target, and return.

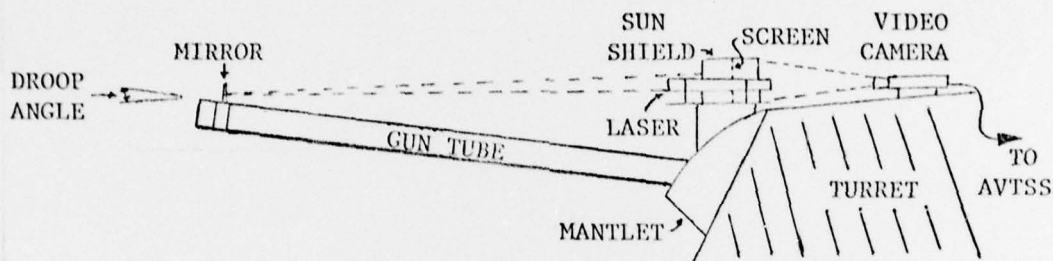


Figure 6 Video Muzzle Position System

The Video Muzzle Position System (VMPS) incorporates the AVTSS to measure gun muzzle movement with respect to the mantlet over a period of time. A small continuous wave laser and translucent screen are mounted on the gun mantlet (Figure 6). A mirror is fastened to the muzzle so that the laser beam is reflected back to the translucent screen. The video camera of the AVTSS is aimed at the back side of the translucent screen and readings are taken by positioning the cursor over the image formed by the reflected laser beam on the screen. The calculator output is angular displacement of the muzzle in mils or other desired scientific units referenced to a position taken at the beginning of testing. Once again, application of video techniques allows this data to be acquired remotely and logged more accurately and rapidly than with other techniques.

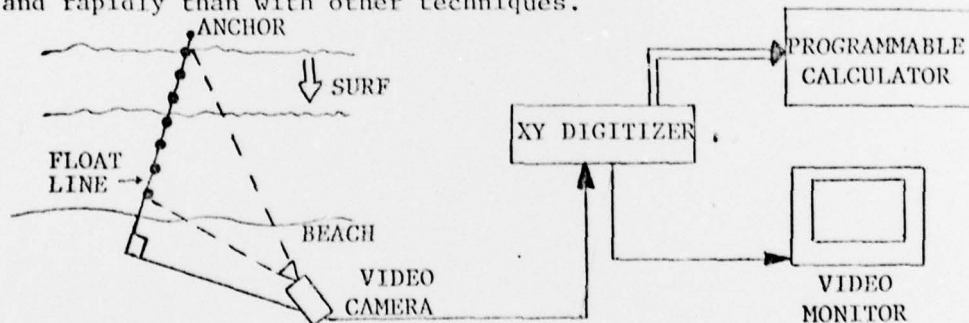


Figure 7 Video Surf Measurement and Analysis System

The Video Surf Measurement and Analysis System was developed to measure the height, velocity, and period of plunging surf throughout an entire surf zone. Testing of a military landing craft required that this data be obtained, however all wave measuring systems in existence prior to the development of the video based system were incapable of measuring surf and could only obtain data for a single location.

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A float line is anchored on the beach and beyond the surf zone (Figure 7). The same components of the AVTSS are utilized with the camera positioned on the beach such that its FOV covers the entire portion of the float line in the surf zone. Previously determined angles and distances are entered into the calculator during calibration. An operator positions the cursor at the peak of a breaker and the float line and digitizes this position. After the breaker passes the cursor is then moved vertically to the float line as it rests at the low water level. The calculator program then accomplishes the necessary trigonometry to calculate the height of the breaker. The addition of a digital time base allows the system to yield breaker velocity by digitizing the same wave crest at two positions, and period, by digitizing two succeeding wave crests at a single position. The calculator also logs the data and performs any analysis as required by the test program.

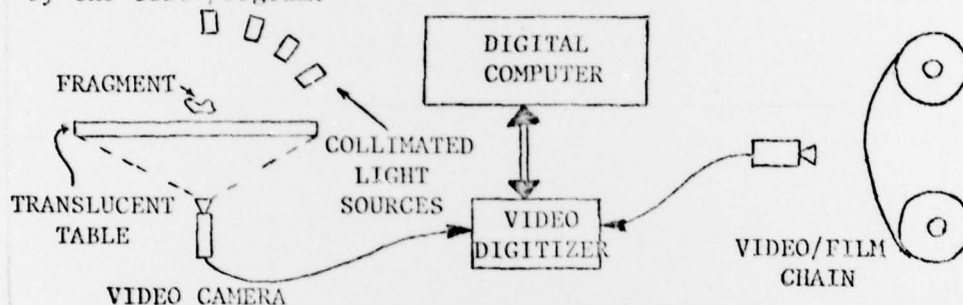


Figure 8 Automatic Video Shell Fragment Area and Velocity Measuring Systems

The Automatic Video Shell Fragment Area and Velocity Measuring Systems are presently under development. Both systems utilize a video camera, a programmable calculator, and a video digitizer (Figure 8). The digitizer allows a single video field to be converted to a matrix of digital words corresponding to the gray scale value of each picture element (pixel) comprising the entire FOV.

To measure shell fragment velocity, a shell is exploded in an arena with dark vinyl sheeting along one side. As the fragments pierce the sheeting a high speed film camera records the holes as light passes through the sheeting from a bank of flash bulbs on the inside. Reading the film frame by frame to determine fragment time and position for velocity calculation is presently a long and arduous task. The video based system will present each film frame to the video camera, digitize the picture, and compare the new picture matrix with that stored in memory from the previous frame thus determining new fragment holes and their location. Data analysis that presently takes days would be accomplished in minutes with the video based system.

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The same system can also measure fragment area. Collimated light sources at several angles project silhouettes of the fragment onto a translucent table above which the fragment is suspended. A video camera is placed below the table so that the silhouettes become video images. These video images are digitized and the computer can then determine the area of the various projections and thus the size of the fragment.

Presently, applications of video to instrumentation are limited by the speed and resolution of the video image devices. As research improves these parameters, the applications of video to instrumentation will greatly increase. Image correlation trackers will become more feasible along with much more extensive processing of the video image. There is an enormous amount of data yet to be extracted from the processing of a video image. The GTV evaluation proves the effectiveness of a video based instrumentation system, and the further applications discussed here are only the beginning.

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